Advanced Energetic Pair Telescope for Medium-Energy Gamma-Ray Polarimetry

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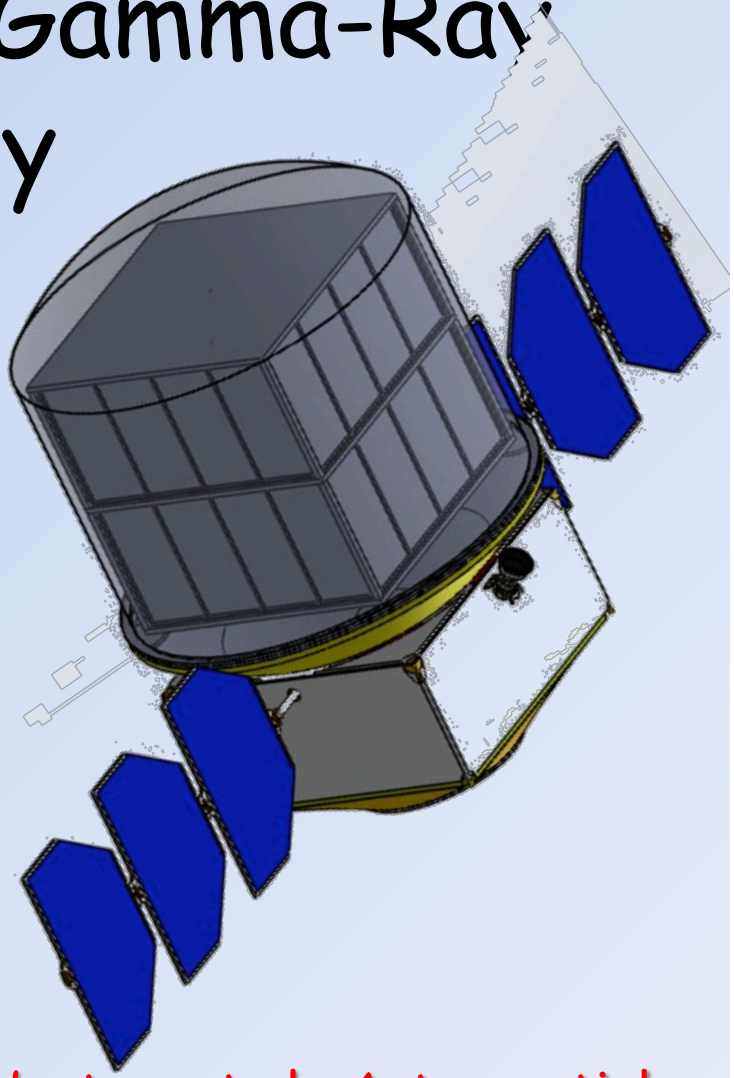
Future Space-based Gamma-ray Obs.
GSFC, Feb. 6, 2015



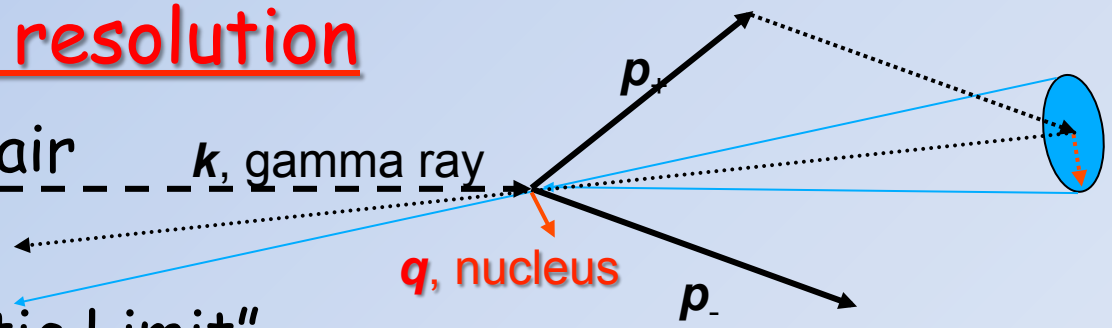
Hunter, et al., Astroparticle Physics, 59, 18-28 (2014)

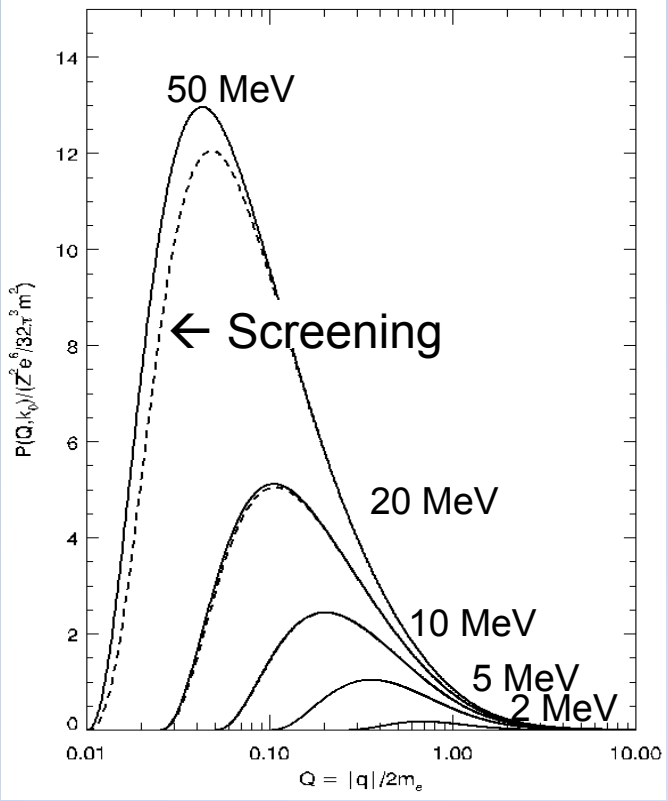
AdEPT Science, 5-200 MeV

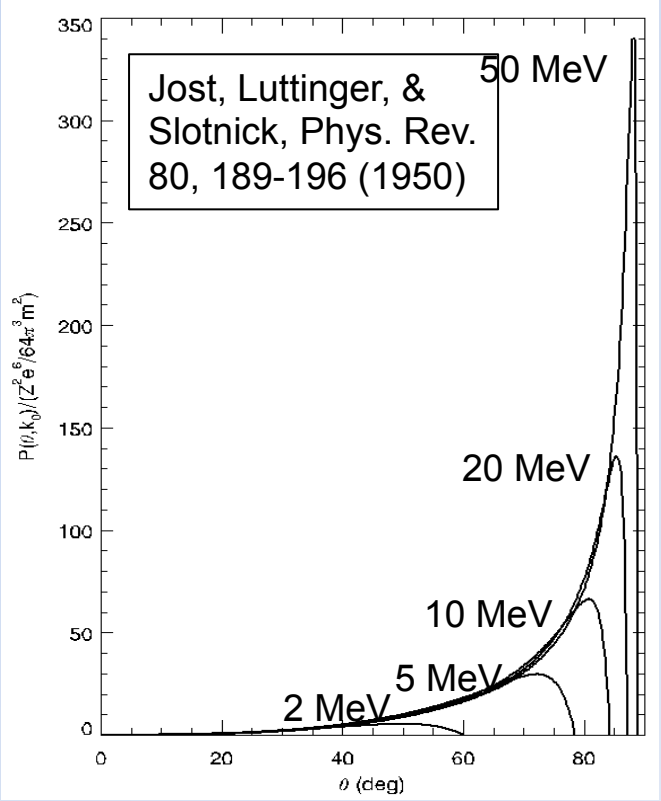
- AdEPT will reveal the configuration of the most energetic accelerators in the Universe
- Explore fundamental processes of particle acceleration in active astrophysical objects
  - Pulsars, pulsar nebulae, supernova remnants, active galactic nuclei, magnetars, accreting binaries, gamma-ray bursts, …
- Map the transition from electronic to hadronic processes in the Galactic diffuse emission
- Probe the universe for exotic processes

AdEPT Design Philosophy

- **Optimize for angular resolution**
  - Angular resolution of pair telescope limited by nuclear recoil, "Kinematic Limit"





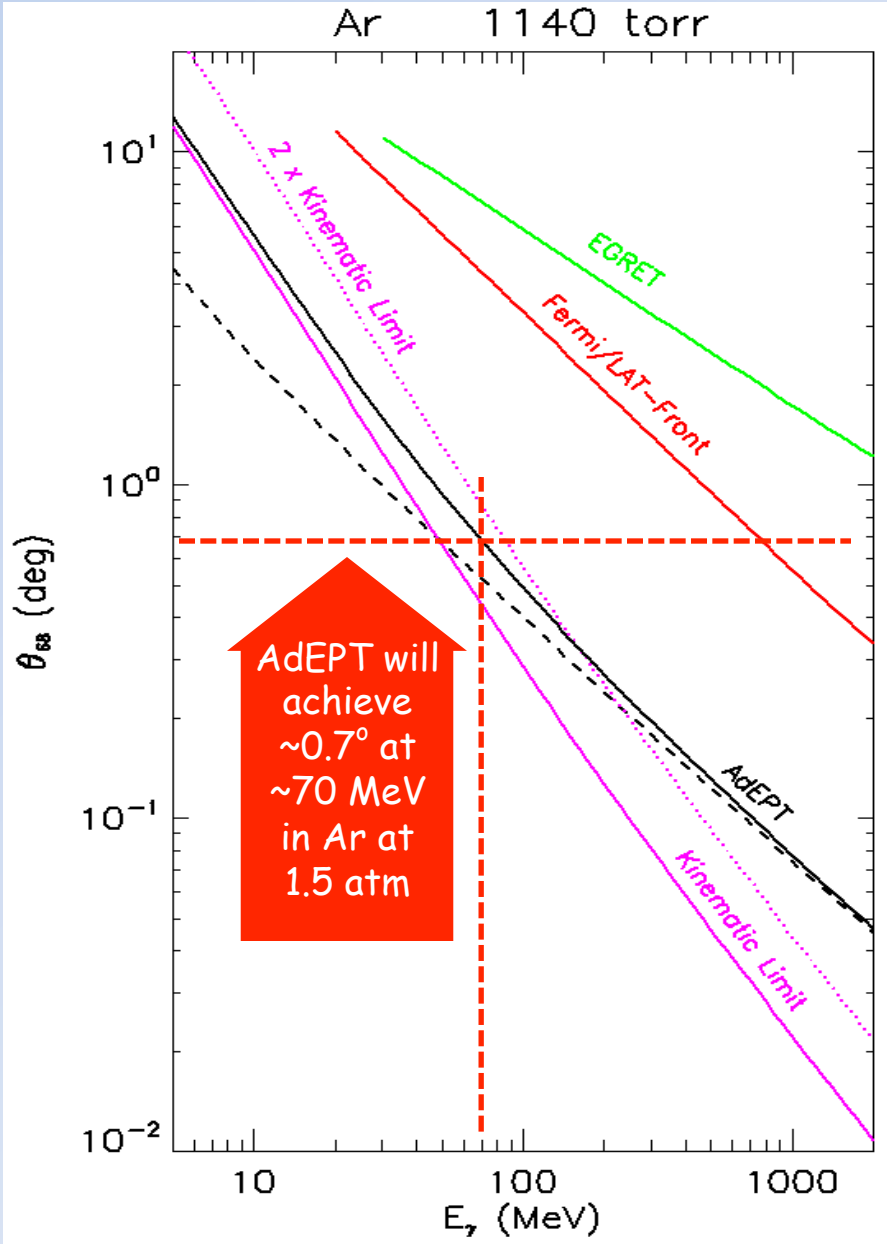


AdEPT Angular Resolution

Achieving angular resolution near the Kinematic Limit

Continuous medium track imager density must be < ~5 mg/cm^3 *i.e. a Gaseous medium*

Hunter et al., Astroparticle Physics 59, 18-28 (2014)



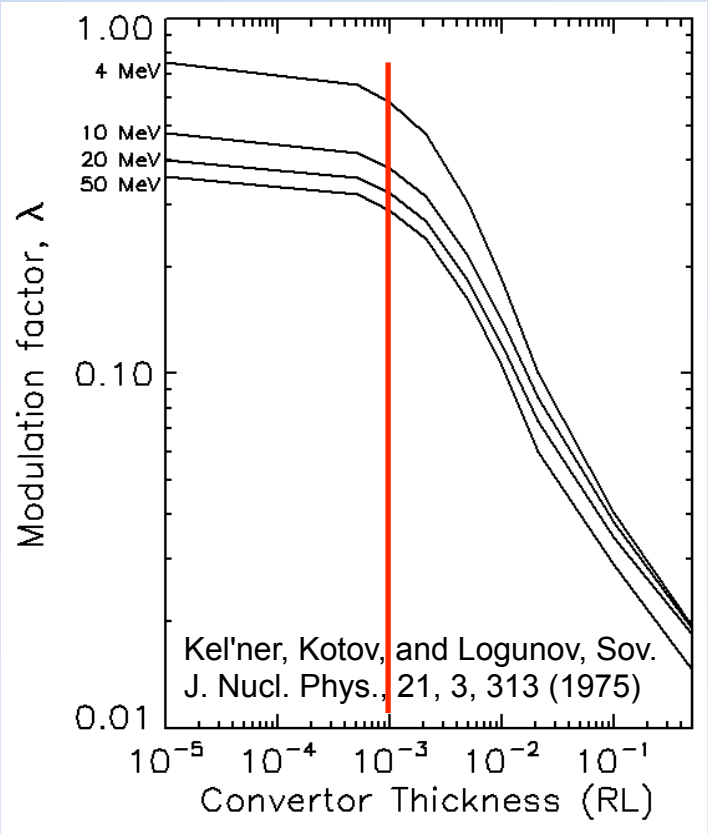
AdEPT Design Philosophy II

- Optimizing for angular resolution
  → polarization sensitivity
  - Modulation factor, λ,

$$\sigma(\varphi) = \frac{\sigma_0}{2\pi}\left[1 + P\lambda\cos^2(\varphi)\right]$$

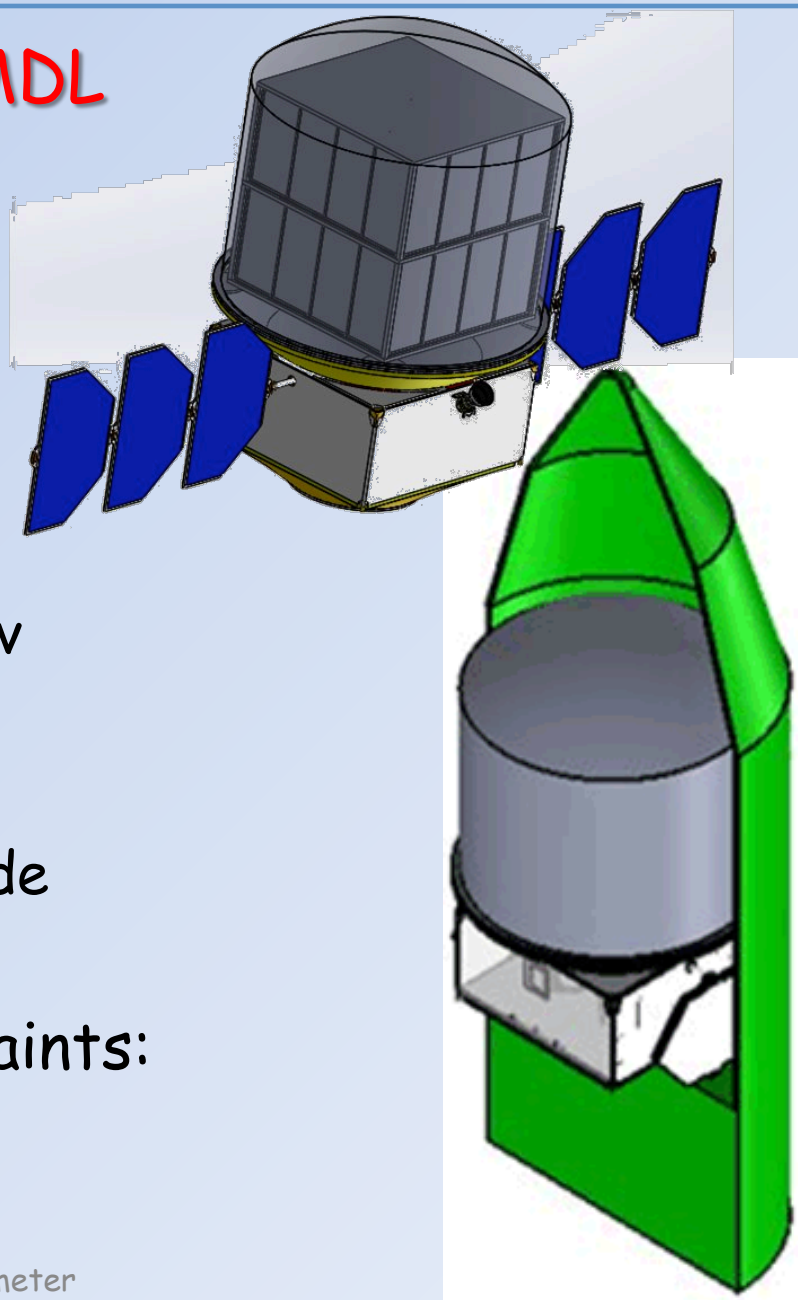
decreases exponentially with thickness of tracking medium above ~1 mRL

- Measure e- and e+ directions in ≲1 mRL
  - ~100 μm of Si
    ~8 cm of Ar at 1.5 atm



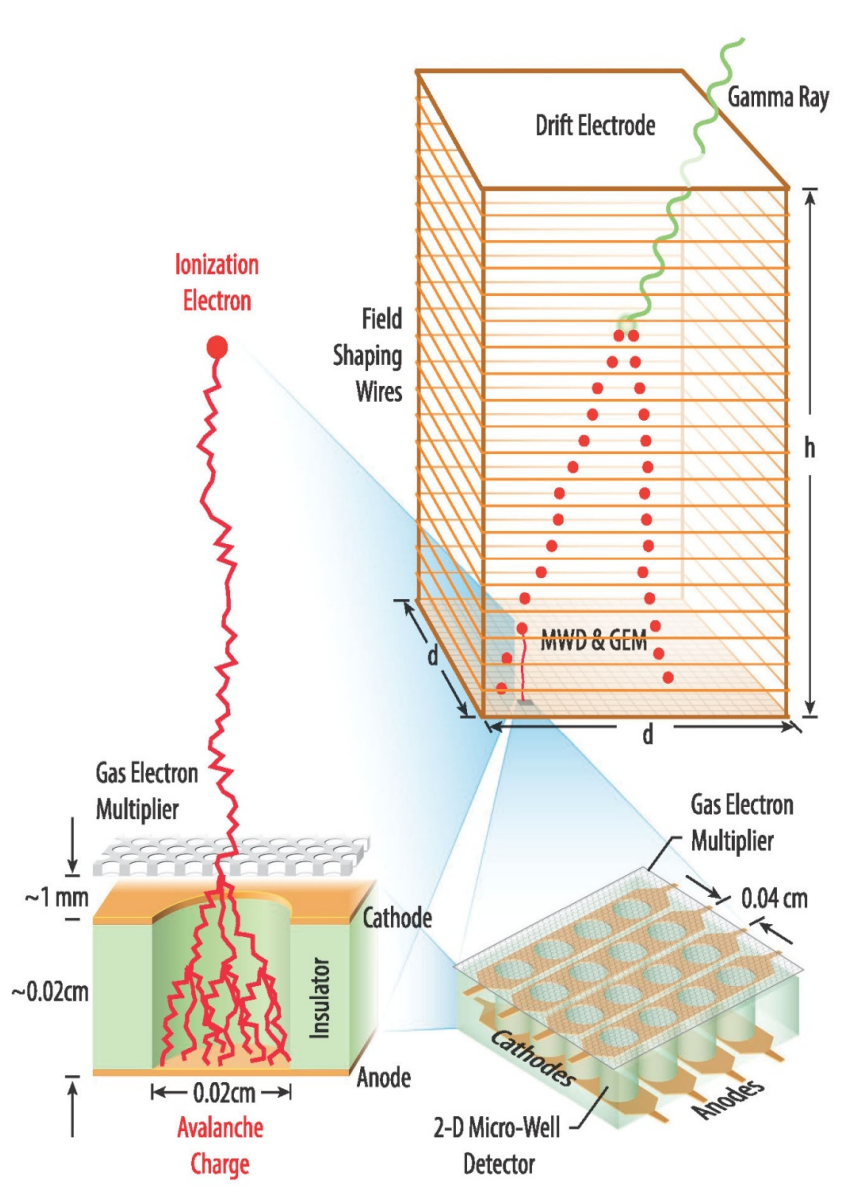
AdEPT is a Viable Gaseous G-ray Polarimeter!

- **Baseline design studied in IDL/MDL**
- 2×2×2 array of 1 m^3 3-DTI modules
  - A_{geom}: 4 m^2, ~40,000 channels
- Ar (1100 torr) + CS_2 (40 torr), 25° C
- Pressure vessel: Al, 4 mm thick, ~300 cm diameter, ~530 kg
- Instrument power: ~500 W,
  mass: ~320 kg w/o s/c, pv
- Spacecraft: zenith pointed, 3-axis stabilized, scanning mode
- Orbit: near equatorial, ~550 km altitude
- Athena launch vehicle
- Fits within Explorer mission constraints:
  Mass, Power, & Cost

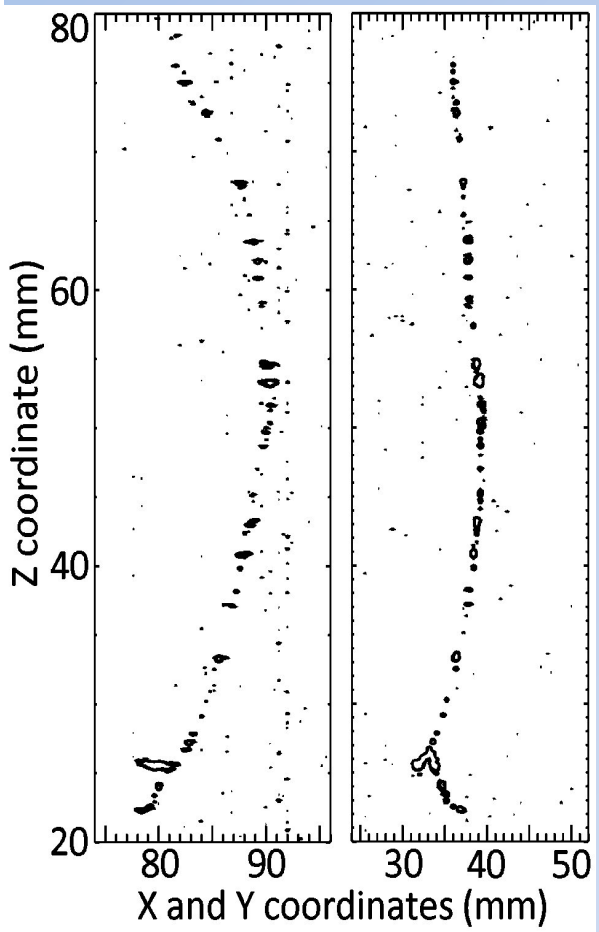


3-Dimensonal Track Imager (3-DTI)

- AdEPT Enabling Technology
  - Large-volume gas **time projection chamber** (TPC)
    - Low density, homogenous, 100% active particle tracking
    - Thermal diffusion achieved with negative ion drift
  - **2-D readout**, 2-D micro-well detector (MWD) + GEM
    - Active detector, 0.4 mm pitch
    - GEM provides additional gain lost to negative ion drift
  - Isotropic medium, scalable to large sensitive volume

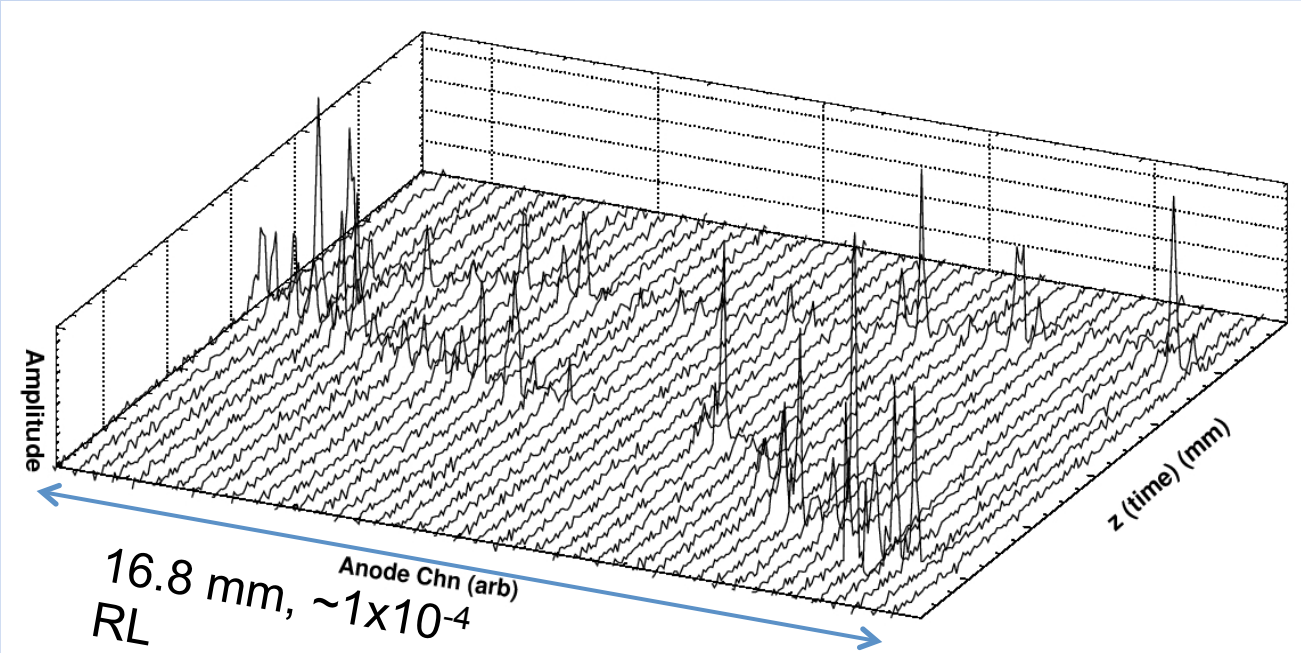


Electron Tracking in 3-DTI



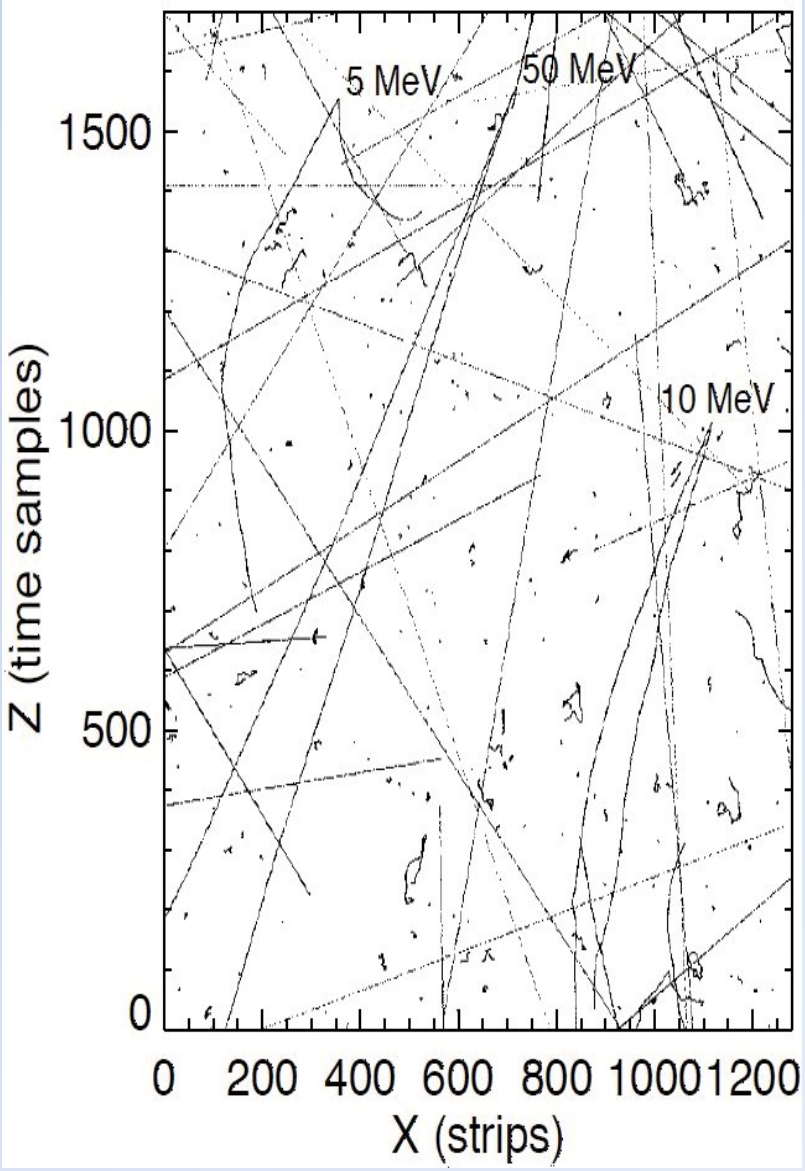
X-Z, & Y-Z projections of single electrons from ^{90}Sr in Ar +CS_2 with 0.4 mm resolution

X-Z projection of 6.129 MeV gamma interaction in 80% P-10 + 20% CS_2

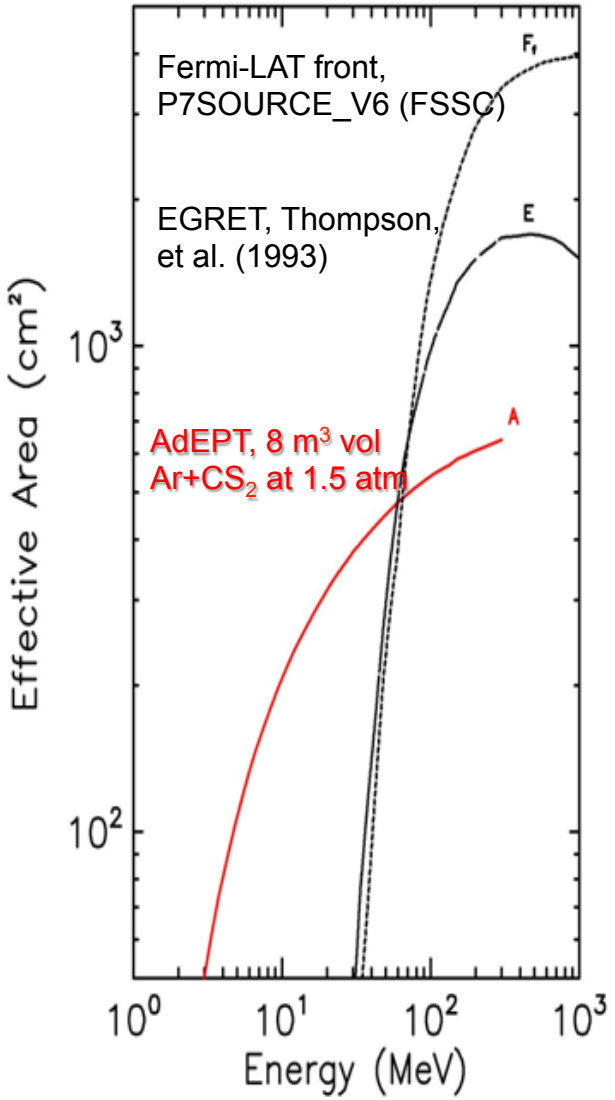


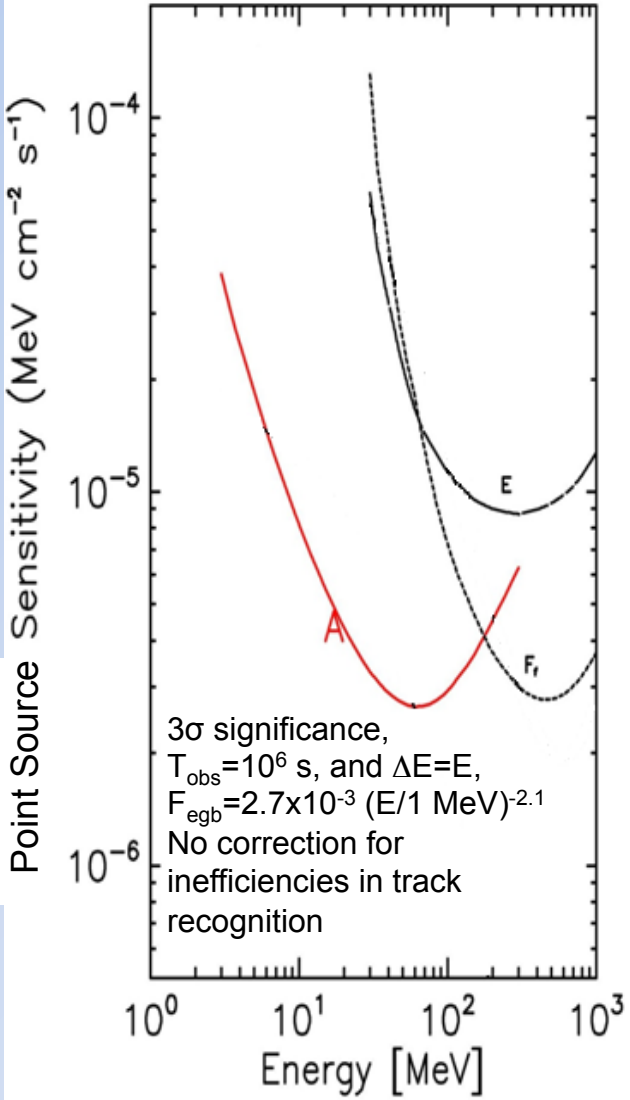
TPC Memory and Data Processing

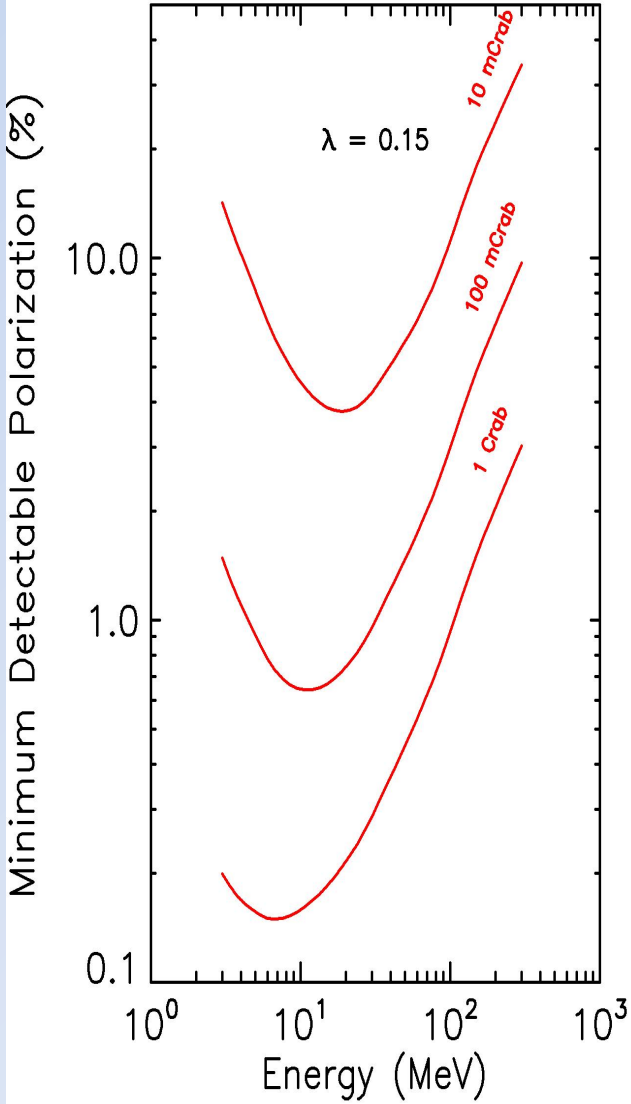
- Ionization charge from all charged particles traversing TPC volume drifts to MWD and is "read out"
- Total drift time is ~50 ms
- Expect ~175 CR protons per m^3 in TPC volume
- Gb/s raw data rate
- Developing simulated data and multi-core on-board processing to discriminate gamma-rays from CRs, low-energy gamma interactions, & noise



AdEPT Baseline Performance

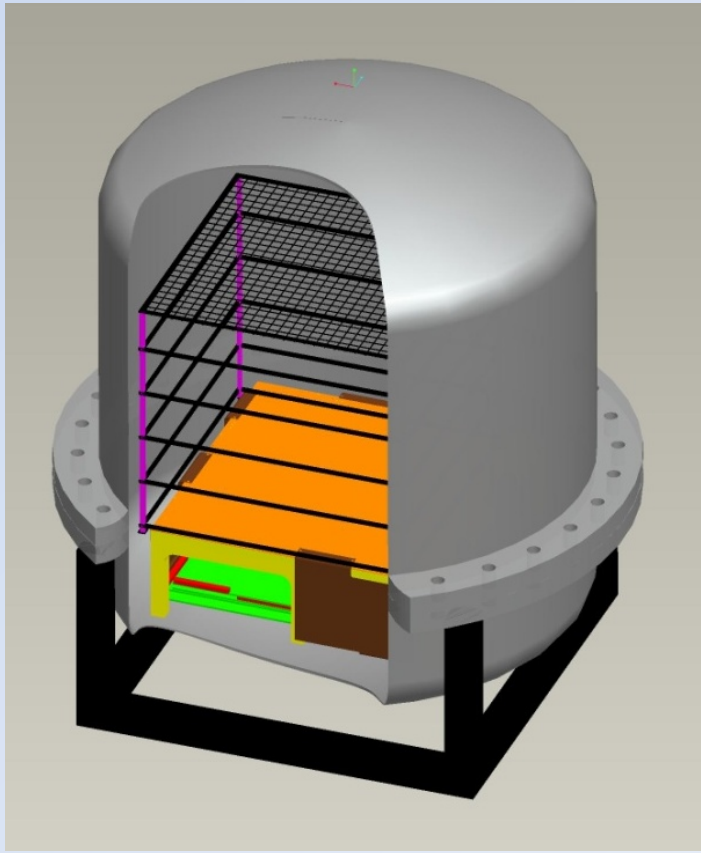






AdEPT Instrument Development

- 2015-18 ROSES-APRA
  - 50 x 50 x 100 cm^3 AdEPT prototype
    - Multi-core processor to discriminate gamma-rays from background
      - Determine gamma-ray direction, energy, polarization, and time of arrival
    - Large area MWD integration
    - FEE ASIC
  - Calibrate at accelerator with polarized gamma rays, 5 - ~90 MeV
    - Determine electron energy from Coulomb scattering
    - Measure angular resolution and Polarization sensitivity



- Future NASA mission!